ME 407: Advanced Thermodynamics

Assignment Submission Date: 22/02/2023

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1. The molar analysis of a gas mixture at 40°C, 3 bar is 50% N_2, 30% CO_2, 20% CH_4. Determine:
   (a) the analysis in terms of mass fractions.
   (b) the partial pressure of each component, in bar.
   (c) the volume occupied by 20 kg of mixture, in m^3.

2. At steady state, a moist air stream (stream 1) is mixed adiabatically with another stream (stream 2). Stream 1 is at 13°C, 1 bar, and 20% relative humidity, with a volumetric flow rate of 0.3 m^3/s. A single stream exits the mixing chamber at 19°C, 1 bar, and 60% relative humidity, with a volumetric flow rate of 0.7 m^3/s. Determine the psychrometric conditions of the stream 2.

3. Air at 30°C and 80% RH is isothermally compressed to 1.0 MPa. Estimate the psychometric condition of the compressed air. If same atmospheric air is expanded to 0.01 MPa, estimate the psychometric condition.

4. A cylinder of an internal combustion engine contains 2450 cm^3 of gaseous combustion products at a pressure of 7 bar and a temperature of 867°C just before the exhaust valve opens. Determine the specific exergy of the gas, in kJ/kg. Ignore the effects of motion and gravity, and model the combustion products as air behaving as an ideal gas.

5. Superheated water vapor enters a valve at 2 MPa and 350°C and exists at a pressure of 0.4 MPa. The expansion is a throttling process. Determine the exergy destruction per unit of mass flowing, in kJ/kg.

6. Steam enters a turbine with a pressure of 30 bar, a temperature of 400°C, and a velocity of 160 m/s. Steam exits as saturated vapour at 100°C with a velocity of 100 m/s. At steady state, the turbine develops work at a rate of 540 kJ per kg of steam flowing through the turbine. Heat transfer between the turbine and its surroundings occurs at an average outer surface temperature of 350 K. Determine the rate at which entropy is produced within the turbine.

7. A counterflow heat exchanger operating at steady state has water entering as saturated vapor at 1 bar with a mass flow rate of 2.5 kg/s and exiting as saturated liquid at 1 bar. Air enters in a separate stream at 298 K, 1 bar and exits at 330 K with a negligible change in pressure. Heat transfer between the heat exchanger and its surroundings is negligible. Determine:
   (a) the change in the flow exergy rate of each stream, in kW.
   (b) the rate of exergy destruction in the heat exchanger, in kW.

8. Steam enters at 540°C, 3 MPa and a velocity of 4 m/s. At the nozzle, the exit pressure is 150 kPa and the velocity is 300 m/s. Determine the rate of exergy destruction in kJ/kg of steam flowing.

9. A pump operating at steady state takes in saturated liquid water at 34 kPa and discharges water at 10 MPa. The isentropic pump efficiency is 75%. Heat transfer with the surroundings and the effects of motion and gravity can be neglected. Determine for the pump:
   (a) exergy destruction, in kJ/kg of water flowing.
   (b) the exergetic efficiency.

10. Determine the specific exergy, in kJ/kg, at 0.01°C of water as a (a) saturated vapor, (b) saturated liquid, (c) saturated solid.

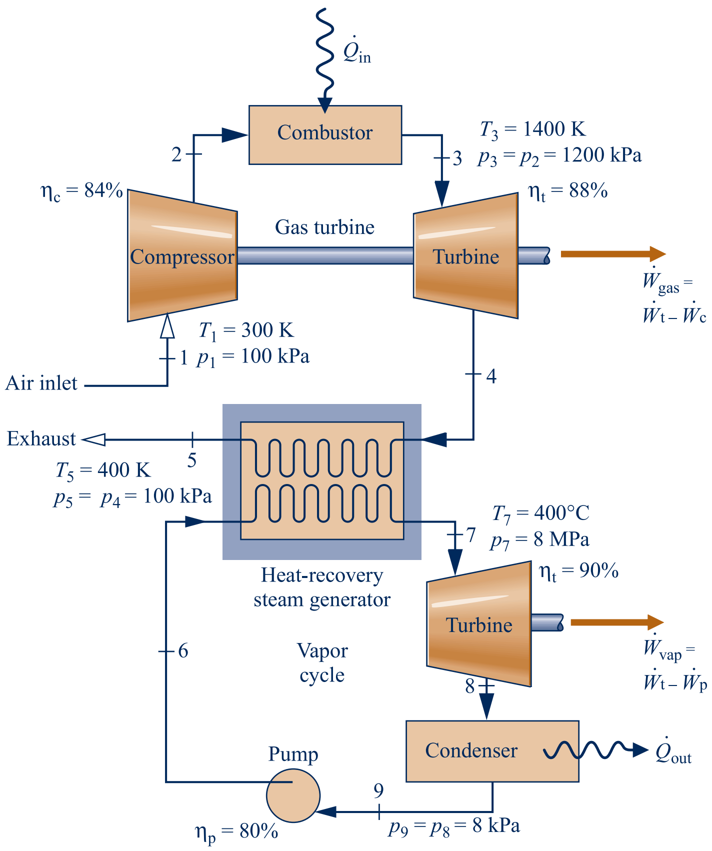
11. A simple steam power plant cycle generates steam in the boiler superheater at 140 bars and 550°C and condenses steam at 0.05 bar. The cooling water required in the condenser experiences a temperature rise from 18 to 28°C. The adiabatic efficiency of the turbine is 80% and that of the pump is 70%. Make suitable energy and exergy analyses for the cycle.

12. Saturated R-134a vapour enters the compressor at 0.2 MPa and leaves the condenser as saturated liquid at 0.8 MPa. Vapour leaves the irreversible compressor at 45°C. Estimate:
(a) COP, (b) Effectiveness of the cycle. Also, prepare energy & exergy balance sheet of the cycle.

13. An irreversible gas-turbine power plant operates between pressures of 1.0 and 6.4 bars with the compressor and turbine inlet temperatures of 25 and 800°C, respectively. Determine:

    (a) the compressor and turbine work
    (b) the heat supplied to the combustor
    (c) the change in exergy across the three devices
    (d) the irreversibility in all the three devices
    (e) Effectiveness of the system

14. Prepare the energy and exergy analyses of a combined cycle power plant using the data shown in the following figure:



15. Show that, for van der Waals gas:

$$\mu_{JT} = \frac{1}{C_p}\left[\frac{RT}{\left(P + \frac{a}{v^2}\right) - (v-b)\left(\frac{2a}{v^3}\right)} - v\right]$$

Estimate the limits of pressure and temperature values for a fluid to achieve cooling upon expansion.